Optimizing Software for the Intel® Pentium® 4 Processor

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Note: Audio start-up may be delayed 1-2 minutes. Stand by.

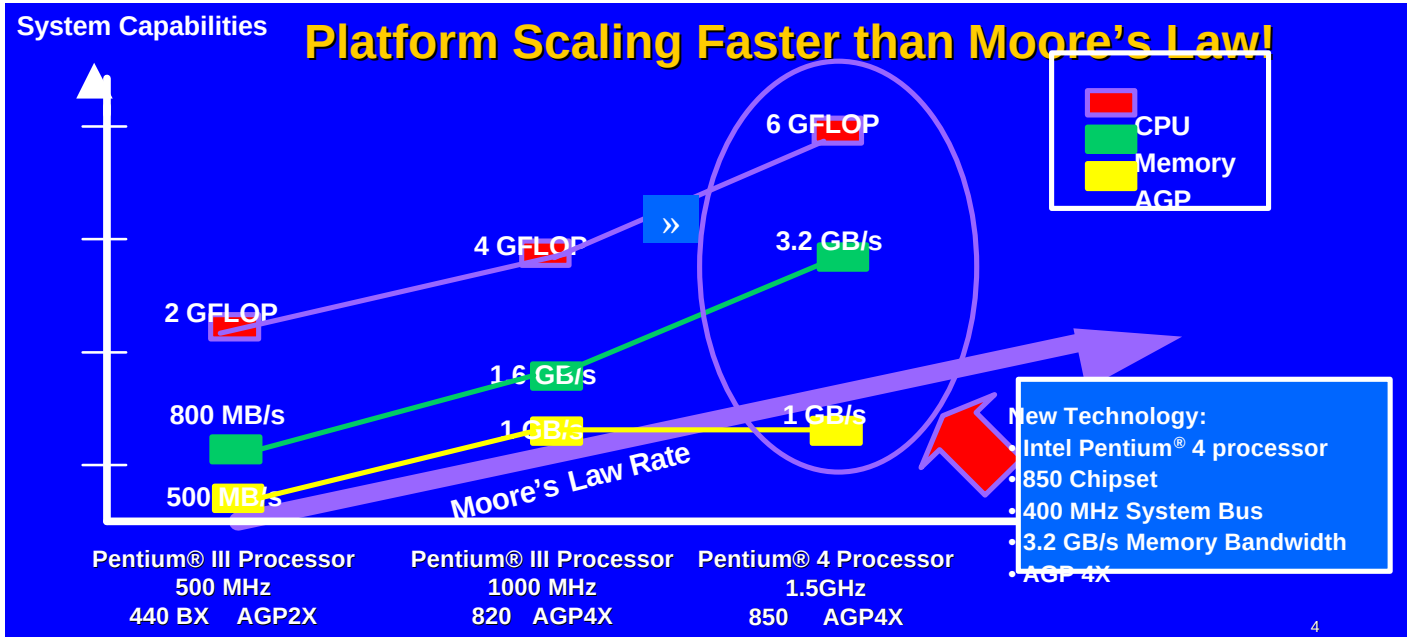
Agenda

- Pentium® 4 Processor System Capabilities
- Performance
- Software Optimizations
- Performance Analysis using VTune™ Analyzer and utilities
  - Case Study: MPEG2 Video Decoder

Please ask questions at any time, in the “Send a Message” box.

Key Pentium® 4 System Platform Capabilities

- New Design Enables Faster Core
  - 1.5 GHz core, future scaling for next several years
  - 6 GFLOPs for fast multimedia performance
- More Bandwidth!
  - 400 MHz System bus => 3.2 GB/sec
  - 128 byte cache lines, 64 byte sectors
  - Better buffering technology
- Streaming SIMD Extensions 2
  - 128 bit Integer plus 2x64-bit DP-FP


System Capabilities
Platform Scaling Faster than Moore's Law!
6 GFLOP
4 GFLOP
2 GFLOP
3.2 GB/s
1.6 GB/s
1 GB/s
800 MB/s
500 MB/s
Moore's Law Rate
CPU
Memory
AGP
New Technology:
• Intel Pentium® 4 processor
• 850 Chipset
• 400 MHz System Bus
• 3.2 GB/s Memory Bandwidth
• AGP 4X
Pentium® III Processor
500 MHz
440 BX AGP2X
Pentium® III Processor
1000 MHz
820 AGP4X
Pentium® 4 Processor
1.5GHz
850 AGP4X

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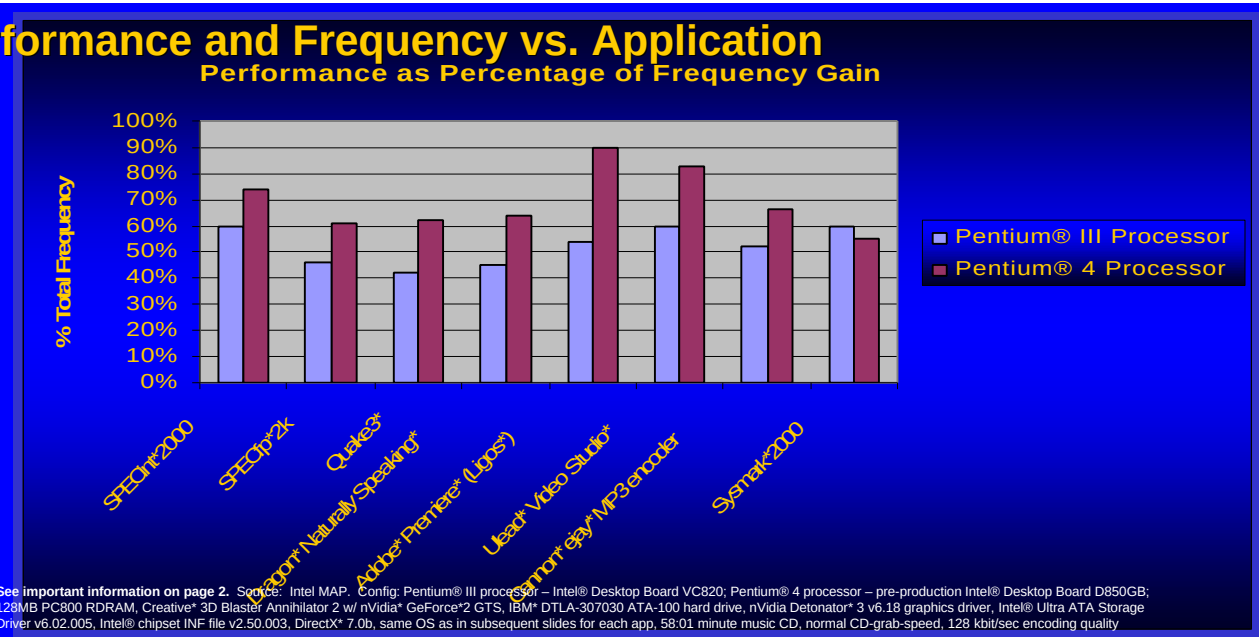
Performance Requirements by App

Performance requirements differ by application area:

- **Integer/Productivity apps (eg, e-mail, word processors) need a human level of response**
  - **Moore's Law improvements in performance sufficient**
- **Multimedia and Internet applications have unbounded need for speed**
  - **MPEG-2, MPEG-4, MP3 encoding**
  - **Real-time video/audio streaming, editing**
  - **3D for games & Ecommerce**
  - **Speech-driven interfaces, dictation, translation**
- **Intel® NetBurst™ micro-architecture matches speed to application area**
  - **Large gains for multimedia, FP, multitasking applications**
  - **1.5x frequency gain vs. traditional architectures on same process**
  - **Platform scalability and headroom into the future**

Performance and Frequency vs. Application



See important information on page 2. Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – pre-production Intel® Desktop Board D850GB; 128MB PC800 RDRAM, Creative* 3D Blaster Annihilator 2 w/ nVidia* GeForce*2 GTS, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02.005, Intel® chipset INF file v2.50.003, DirectX* 7.0b, same OS as in subsequent slides for each app, 58:01 minute music CD, normal CD-grab-speed, 128 kbit/sec encoding quality

Performance and Frequency

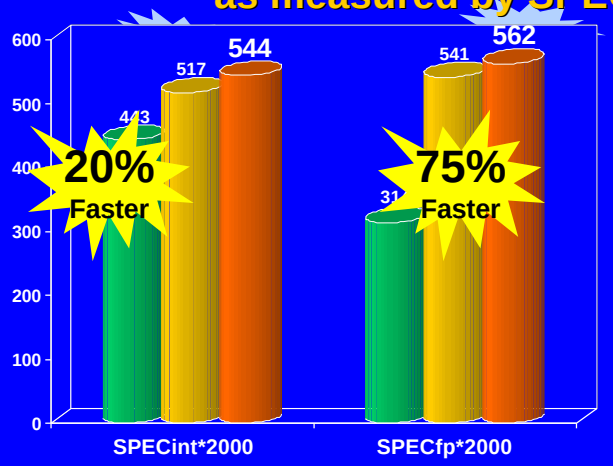
- **Performance scaling varies per application**
  - Execution may be sensitive to computation, bandwidth or system I/O (disk, network, graphics H/W)
  - Different types of code (integer, floating-point, or MMX™ technology) also have different execution characteristics
- **Older processor architectures eventually show their age**

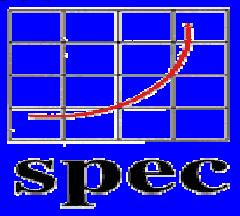
Pentium® 4 processor gives a quantum boost in frequency AND is more efficient in using that gain

Performance

HIGHEST PERFORMANCE Desktop Processor

as measured by SPEC* CPU2000





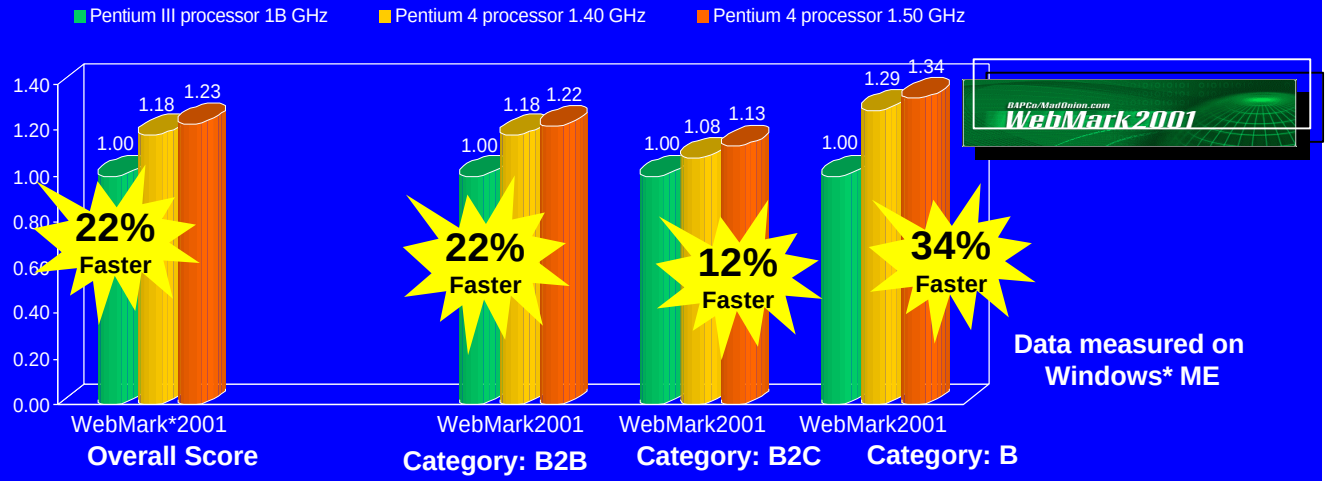
- Pentium III processor 1B GHz
- Pentium 4 processor 1.40 GHz
- Pentium 4 processor 1.50 GHz

Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – Intel® Desktop Board D850GB; 256MB PC800 RDRAM, Creative* 3D Blaster Annihilator 2 w/ nVidia* GeForce*2 GTS, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02, Intel® chipset INF file v2.50, DirectX* 7.0b, Windows* 2000, Intel® Compiler 5.0

** SPEC CPU2000 data is available at http://www.spec.org

Performance

Best for the Visual Internet



Data measured on Windows* ME

Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – Intel® Desktop Board D850GB; 128MB PC800 RDRAM, Creative* 3D Blaster Annihilator 2 w/ nVidia* GeForce*2 GTS, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02, Intel® chipset INF file v2.50, DirectX* 7.0b, Windows* Millennium*, 100 Mbps LAN, Apple* QuickTime* 4.1.1

Audience Poll: What type of Application ?

What types of applications do you develop ?

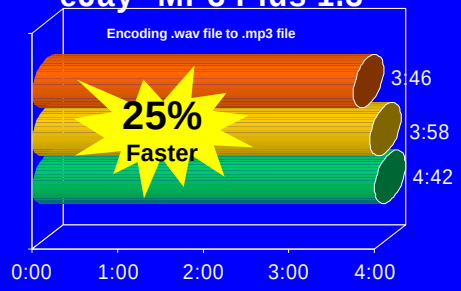
- Integer/personal productivity
- 3D graphics
- Audio and/or video
- Scientific and/or floating-point
- Database and/or data-mining
- other

Performance

MP3 Encoding

- Pentium® 4 processor 1.50 GHz
- Pentium 4 processor 1.40 GHz
- Pentium® III processor 1B GHz

eJay* MP3 Plus 1.3



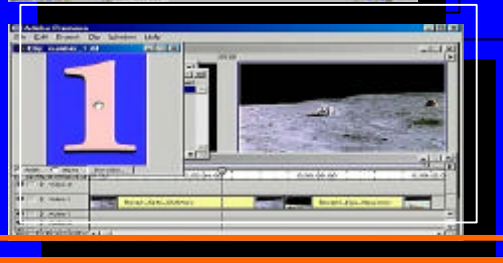
A Shorter Bar is Faster

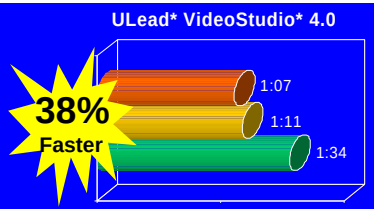
Save almost 1 minute for every music CD you encode

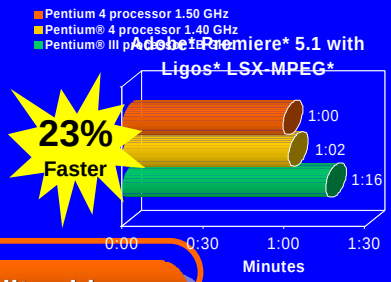
See important information on page 2. Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – Intel® Desktop Board D850GB; 128MB PC800 RDRAM, Creative* 3D Blaster Annihilator 2 w/ nVidia* GeForce*2 GTS, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02, Intel® chipset INF file v2.50, DirectX* 7.0b, Windows* Millennium*, .wav file created from full-length music CD "Bernstein Century – Beethoven: Symphony No. 9" available on the Sony Classical label, normal CD-grab-speed, 128 kbit/sec encoding quality

Performance

Video Editing







Quickly create, edit, and share professional quality video

A Shorter Bar is Faster

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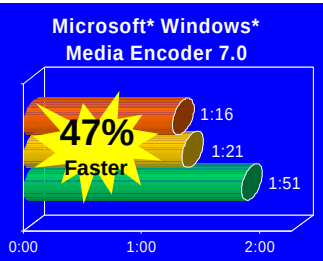
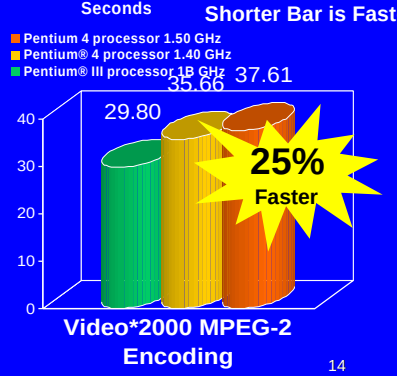
Performance

Video Encoding

Greater speed in making high quality video





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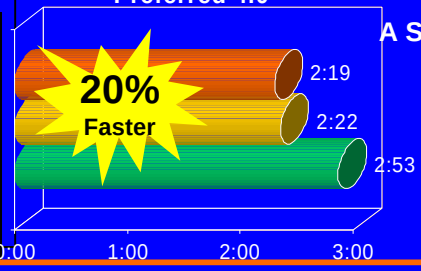
Performance

Speech Recognition

Pentium® 4 processor 1.50 GHz
Pentium 4 processor 1.40 GHz
Pentium® III processor 1B GHz

Dragon* Naturally Speaking* Preferred 4.0



A Shorter Bar is Faster

Improved performance = faster voice training and speech-to-text translation

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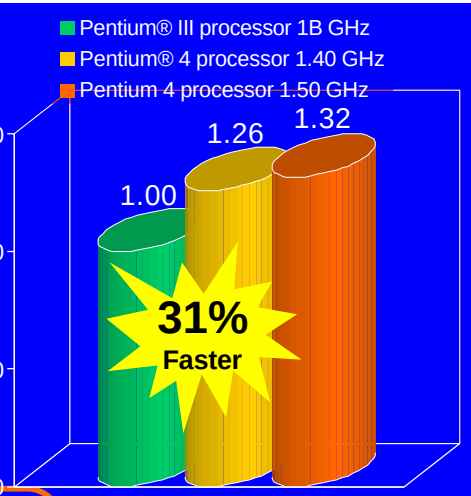
Performance

3D Graphics



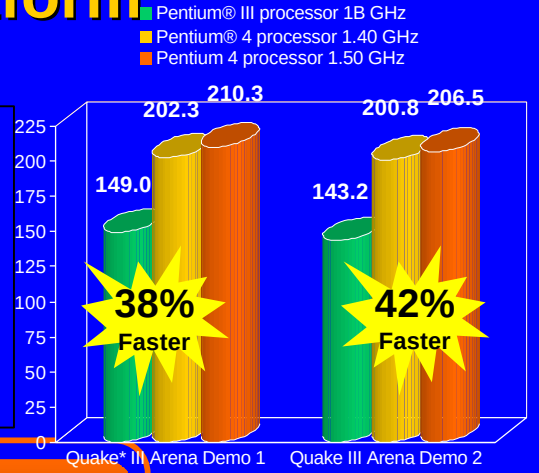
Great performance gain for 3D graphics

Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – Intel® Desktop Board D850GB; 128MB PC800 RDRAM, Creative* 3D Blaster Annihilator 2 w/ nVidia* GeForce*2 GTS, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02, Intel® chipset INF file v2.50, DirectX* 7.0b, Windows* Millennium*

Performance

Fast 3D Gaming Platform

-- Quake* III Arena --



Performance boost for today's hottest online games

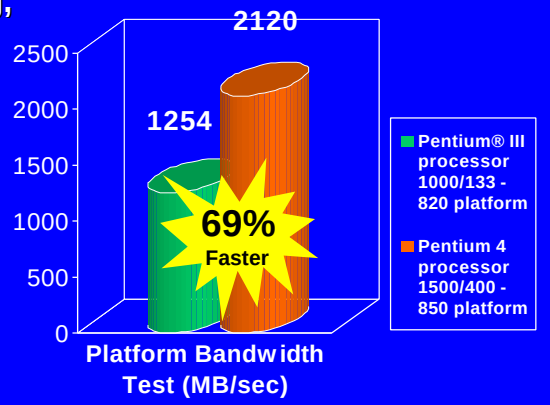
Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – Intel® Desktop Board D850GB; 128MB PC800 RDRAM, Creative* 3D Blaster Annihilator 2 w/ nVidia* GeForce*2 GTS, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02, Intel® chipset INF file v2.50, 640x480 resolution at 16-bit color, DirectX* 7.0b, Windows* Millennium*

Performance

Platform Bandwidth

- Increasing integration of speech, digital imaging, audio, video, and 3D in both Internet software and business productivity software
  - Bigger data sets need maximum platform bandwidth
- Platform Bandwidth Test v2.0 demonstrates increased bandwidth that the Intel® 850 offers applications

PLATFORM BANDWIDTH TEST



+ Platform Bandwidth Test v2.0: This test is designed to highlight the benefits of the Intel 850 platform. It measures sustained system bandwidth from concurrent CPU and AGP traffic. The test only runs on nVidia* TNT2* and GeForce* based graphics cards. The performance of this synthetic test may not be representative of that of actual applications. Therefore, the actual application performance that users experience may vary. For more information on performance tests, see www.intel.com/procs/perf/limits.htm. *Third party brands and marks are property of their respective owners.

Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – Intel® Desktop Board D850GB; 128MB PC800 RDRAM, Creative* 3D Blaster Annihilator Pro AGP w/ nVidia* GeForce*256 DDR, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02, Intel® chipset INF file v2.50, DirectX* 7.0b, Windows* Millennium*

Quick Quiz: Application Speedup?

Which 2 benchmarks showed the most speedup for the Pentium® 4 processor ?

- **Webmark2001***
- **Quake* III Arena**
- **MP3 Encoders**
- **Video Editors**
- **Platform Bandwidth**

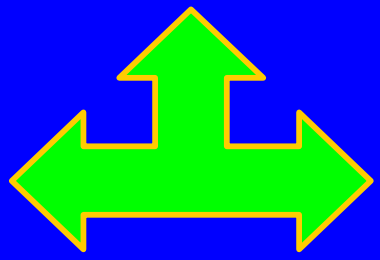
Agenda

- Pentium® 4 Processor System Capabilities
- Performance
- ⇨ Software Optimizations
- Performance Analysis using VTune™ Analyzer and utilities
  - Case Study: MPEG2 Video Decoder

Key Optimization Messages

- Optimizations often
  - few in number
  - localized in extent
  - easy to implement
  - Benefit for both Pentium® III and Pentium 4 processors
  - good performance ROI (1.1x-1.3x)
- Two key categories:
  - Data Movement
  - Computation
- VTune™ Analyzer and pDiff
  - easily identify and estimate optimization benefits

Data Movement



- Main issues:
  - Avoid stalls (1.1-1.3x gain):
    - Cache line and buffer alignment
    - Store-to-load forwarding
  - Prefetching (1.1-1.3x gain)
  - Optimal Data Structure Access (1.1-1.3x gain)
  - Ensure full BW to graphics HW (1.1-1.2x) with WC memory
- Many optimizations apply to both Pentium® III and Pentium® 4 Processors

Cache Line and Buffer Alignment

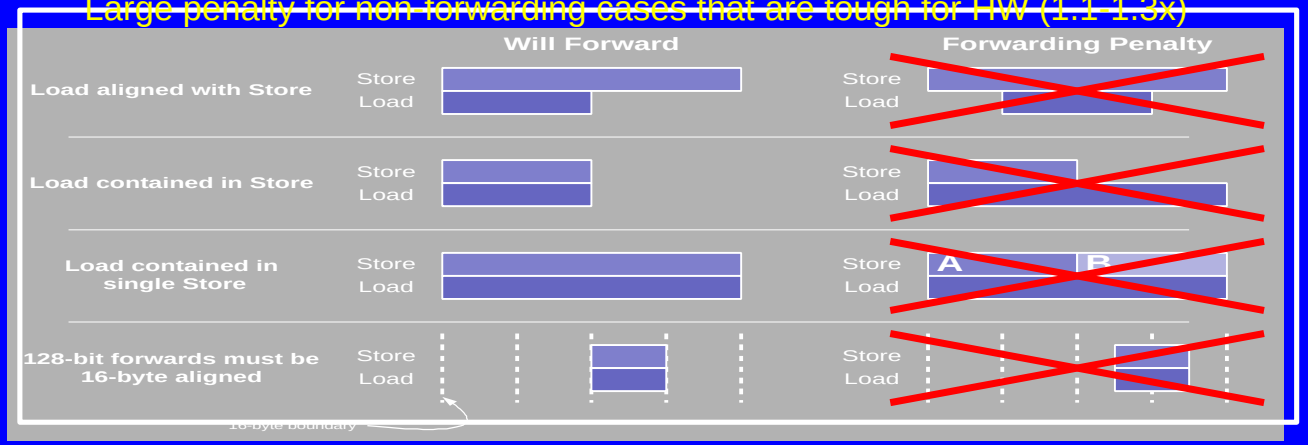
- Avoid cache-line cross-over on loads (1.1-1.2x gain)
  - Align data structures to 16 or 32B, including arrays passed to 3D APIs
  - Misalignment penalty is bigger on Pentium® 4 Processors
- Avoid concurrent access to buffers whose addresses are offset by multiples of 64k-bytes (1.05-1.1x gain)
  - Contention for same resources can result in a stall
  - Offset one of the buffers if possible:

```
If ((PtrA & 0xFFFF) == (PtrB & 0xFFFF)) {
 PtrB += 0x1000;
}
```

Store-to-load Forwarding Guidelines

Store-to-load forward: Load to address recently stored causes data to be bypassed.

~~Large penalty for non-forwarding cases that are tough for HW (1.1-1.3x)~~



Intel Compiler, MSVC*7.0 help avoid these cases

Prefetching Data

- Prefetch hides memory latency behind computation
- Pentium® 4 processor HW prefetcher may automatically achieve benefits
  - Triggers on regular access patterns
  - Works well with larger data structures
- But software prefetching may help further…
  - Can benefit less regular, smaller data structures
  - PrefetchNTA instruction is often best (1.1-1.15x gain)
    - Reduces cache evictions of useful data
    - Maximizes read-bandwidth to system memory

Prefetching (cont)

- Does the Pentium ® 4 processor change SW prefetching?
  - No, same considerations apply.
  - Pentium III processor approach of 1 prefetch/32Byte data works.
    - Prefetch per 8- or 16-B may be inefficient (overkill)
  - Same choice for type and location of prefetch within a program
  - Increase fetch-ahead distance as memory vs computation latency increases.

Experiment to Optimize Prefetching !

Optimal Data Structure Access

- Longer Pentium® 4 Processor cache lines
  - 64-byte lines, and generally access 128-bytes per bus request
  - So try to avoid sparse data structures (1.1-1.3x gain)
- Use DQWord loads/stores (1.1x gain):
  - Best utilization of cache and buffering resources
  - Achieves maximum bandwidth for memory copies

Optimal Data Structure Access (cont.)

- Use hybrid SOA (Structure of Arrays) for best DRAM efficiency (1.1x gain)
  - Improves utilization of fetched lines, especially with longer Pentium® 4 Processor cache line size
    - More useful data in a given line
    - Fits SIMD parallel computation (e.g., RGB pixels)
  - Fewer DRAM page misses

```
struct { //Array_Of_Struct
   float  x, y, z, r, g, b;
} AoS_xyz_rgb[200];
```

```
struct { //Struct_Of_Array
   float  x[200], y[200], z[200];
   float  *rptr, *gptr, *bptr;
} SoA_xyz_rgb;
```

```
struct { //Hybrid_Struct_Of_Array
   float  xx[4], yy[4], zz[4];
} Hybrid_xyz[50];
struct {
   float  rr[4], gg[4], bb[4];
} Hybrid_rgb[50];
```

What is Write-Combining?

- Uncacheable writes to memory with the WC attribute are allowed to be combined within the processor.
- Goal: fewer & larger burst accesses on the bus
  - Ideally, completely filled buffers that go out as single bus transaction.
- Pentium® III & Pentium 4 processors have 32 & 64 Byte WC buffers
- WC attribute generally applied to AGP system memory and graphics card local memory for 2D/Video & 3D usage

Write Combining Buffer Usage

- **For maximum performance:**
  - **Isolate WC writes from memory activity competing for same WC buffer**
    - Competing traffic can close a WC buffer before all writes to buffer finish, resulting in a series of 8-Byte partial bus transactions rather than a single 32/64 Byte write
    - **For Pentium® III processor, L1-cache-missing loads and stores need to be separated from WC writes**
    - ***For Pentium 4 processor, stores need to be separated from WC writes.***

Partial writes reduce realized front-side bus BW ~3x for Pentium III processor but ~7x lower for Pentium 4 processor (due to longer 64-byte line)

Software Write-Combining

- Same approach for Pentium® III and Pentium 4 processors
  - Driver writes data to a small cacheable Temp buffer fitting in the L1 cache
  - When the buffer fills up, driver quickly copies from the Temp buffer to WC
- Best Performance:
  - Reads and writes are separated, reducing the turn-around dead clock occurrences between
  - Write multiples of 64-bytes to avoid WC partial writes
  - Collect enough data in cacheable Temp buffer to minimize branch miss-prediction impacts

Ensures best utilization of HW write-combining resources

Quick Quiz: Data Movement

Which 2 of the following should NOT be data movement optimization considerations ?

- Write-after-write hazards
- Store-to-load forwarding
- Write combining memory allocation
- Instruction Prefetching
- Alignment to 64-byte cache line boundaries

AGP Considerations

- Ensure AGP enabled
  - New chipset .inf driver file for 850
- Pentium® 4 Processor Bandwidths:
  - 2 GB/s WC (write-combining) BW to memory on system bus (DMA)
  - CPU to AGP BW:
    - ~700 MB/s with fast writes enabled (1/3 peak)
    - ~180 MB/s with fast writes off (1/10 peak)
    - Enable Fast-Writes if supported, but…

DMA model is best

Computation Optimizations

Main issues:

- Use Streaming SIMD Extensions 2 instructions, where appropriate
- Denormal Exceptions
- Other FP considerations
- Int Rotate / shift latency

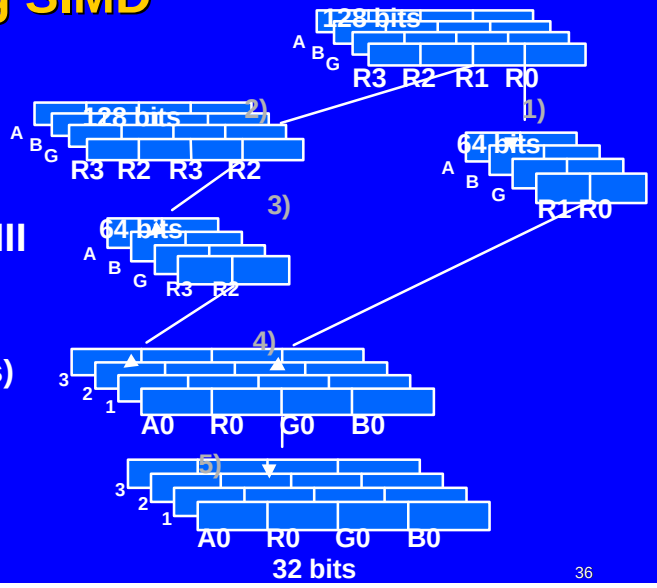
Computation

Streaming SIMD Extensions 2

- New 128-bit SIMD Integer instructions
  - Aimed at pixel-processing apps (photo and video editing), audio and speech processing, encryption algorithms
  - Superset that extends MMX™ technology instructions from 64- to 128-bits
  - New 128-bit SIMD-Integer instructions
    - Packed 32 * 32 bit Multiply
    - Packed 64 bit Add/Subtract
    - Shift, Shuffle, Unpack, Move, Conversion
- New SIMD Double Precision FP instructions
  - For apps that need higher FP range
    - EG, 3D content creation, modeling, real-time physics
  - Full complement of FP arithmetic operations
  - Packed/Scalar DP ⇔ SP conversions

Color conversion: Streaming SIMD Extensions

- In 3D Lighting, colors converted from FP to packed bytes
- The algorithm for Intel® Pentium® III processors is:
  - Convert two color components
  - Shuffle the colors (High to low portions)
  - Convert two more
  - deSwizzle
  - Pack & Saturation

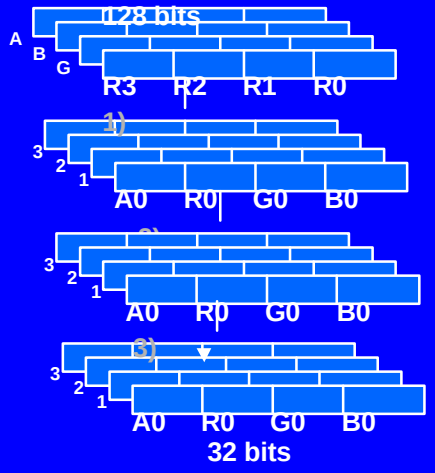


Color conversion: Streaming SIMD Extensions 2

The algorithm for the Pentium® 4 processor:

- deSwizzle
- Convert color components for four vertices (using SSE2 instructions)
- Pack & Saturation (using SSE2 instructions)

1.1-1.15x performance gain



Quick Quiz: Streaming SIMD Extensions 2

The Streaming SIMD Extensions 2 include which 3 of the following 5 features ?

- 128-bit integer operations
- 256-bit integer multiply
- 128-bit shift, shuffle, unpack
- Double-precision floating-point add and multiply
- Colorspace conversion instructions

Denormal Exceptions

- Some computations create values very close to zero
  - Output: After an arithmetic op yields de-normal value result
  - Input:
    - This result may be used in a subsequent op.
    - May also result from constants, coefficients, etc
- Both cases can cause a large performance loss due to specialized micro-code handling
- Workaround: set appropriate fast-execution mode (~1.1-1.5x gain)
  - FTZ: Flush output denormals to zero
  - DAZ: Flush input denormals to zero
- Using these modes, along with masking all exceptions, enables real-time execution

Additional Considerations

- X87-FP
  - Serialization penalty is greater for FLDCW
    - Avoid changing for FP->Int conversions (1.1-1.3x gain)
  - Transcendentals (FSIN, FCOS, etc) have longer latencies
    - Use approximations (series expansion, lookup)
    - Intel's math libraries use high-precision implementations (up to 2x performance gain)
- Integer shifts/rotates have longer latencies
  - Software unrolling can interleave independent computation (1.1-1.3x gain)

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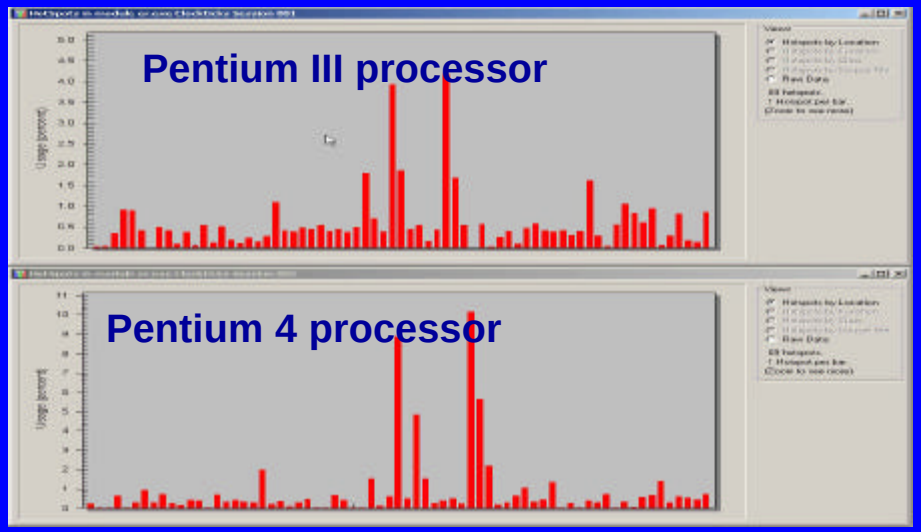
VTune™ Analyzer and pDiff Technique

- Different workload sections scale by different amounts
  - Integer code: branchy, may scale ~1.2x
    - » Miss-predicted branches can offset frequency gains of deeper pipelining
    - » Greatly improved HW branch prediction – but still a big challenge for any very deeply pipelined processor
  - FP/MMX code: less branchy, scales ~1.3-1.7x
  - Some execution time may be constant (eg, graphics stalls, disk I/O, timing loops)
- How to identify what code to focus on?
- How to estimate benefit for recoding?

How to identify what code to focus on?

- Capture 2 time profiles
  - Pentium® III vs. Pentium® 4 processor
- Run through “pDiff” utility
- Interpret results in Excel*



How to estimate benefit for recoding?

Case Study: MPEG-2 video decode

Module/DLL				Function				Instr Bin				Optimized
Name	PIIIP	P4P	Scaling	Name	PIIIP	P4P	Scaling	EIP	PIIIP	P4P	Scaling	Scaling
decode.dll	60%	65%		[illegible]	5%	15%	1.1	0x[illegible]-0x[illegible]	5%	15%	1.1	1.4
grfx_driver.dll	25%	30%		memmove	25%	30%	0.5	0x4fc40-0x4fc80	25%	30%	0.5	1.4
app.exe	10%	4%	1.4	SplitStream	3%	1%	1.4	0x96540-0x96580	3%	1%	1.4	1.4
GDI32.DLL	5%	1%	1.2	SaveDC	1%	1%	1.2	0x21f40-0x21f80	1%	1%	1.2	1.2
Total	100%	100%	1.05									1.45

- Scaling shown in Excel* for Module, Function & Instr Bin
- Quickly identifes key code sections that are scaling poorly
- Estimate app-level gain for optimization by adusting scaling on a given localized instruction bin

Results from MPEG-2 Video Decoder Optimization

- VTune™ Analyzer and pDiff quickly identified main issues:
  - Frame-rate locked to refresh (fix via double-buffering)
  - AGP fast-writes not enabled by graphics driver
  - VLD recoded to minimize integer shifts & muls
- Addressing these issues resulted in:
  - 1.4x performance gain vs. initial code
  - 1.45x performance gain Pentium® 4 processor over Pentium® III processor

Quick Quiz: Tools for Optimization

True or False:

- The quickest way to optimize for Pentium® 4 processors is to compare performance to a Pentium® III processor using pDiff

Summary

- Pentium® 4 processor matches performance to application area:
  - Integer/productivity apps need human-level response: ~1.1-1.2x Moore's Law gain
  - Multimedia/FP apps need unbounded performance
    - ~1.25-1.7x compared to current processors
- Performance will increase as apps get optimized for the processor
- Optimizations tend to be few in number, localized in extent

Summary (cont.)

- Key optimizations:
  - Avoid stall cases
  - Avoid exceptions (eg, denormals)
  - Appropriate use of SSE2 (eg, 3D lighting)
  - Efficient graphics bandwidth utilization
- VTune™ Analyzer and pDiff techniques can quickly identify optimizations that yield big gains

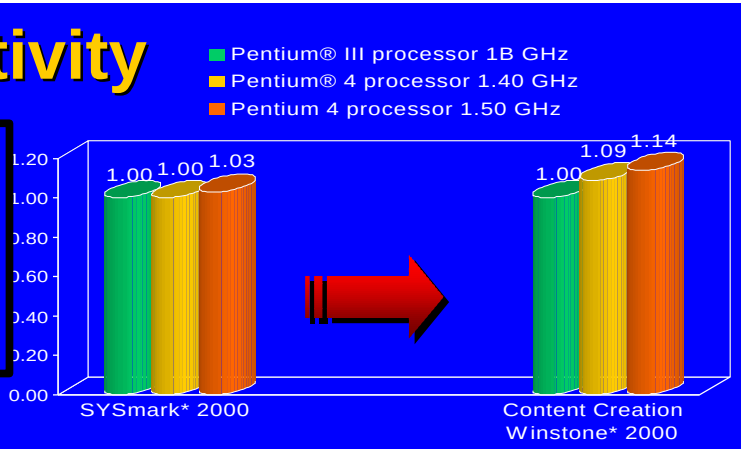
Next Steps

- Check out http://developer.intel.com/design/pentium4/ and http://developer.intel.com/software/idap/training/ for more detailed information
- Optimize your applications for Pentium® 4 processors
- Please fill out our webcast course evaluation !!

Backup Materials

Productivity

Preliminary



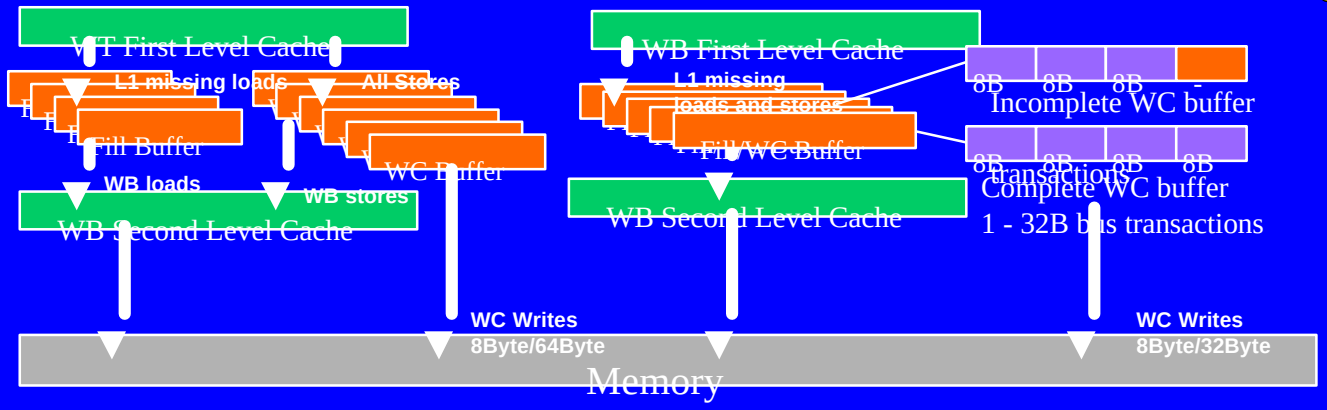
Great performance for basic office applications

Greater gains for power hungry Internet publishing applications

Source: Intel MAP. Config: Pentium® III processor – Intel® Desktop Board VC820; Pentium® 4 processor – Intel® Desktop Board D850GB; 128MB PC800 RDRAM (except 256MB for Content Creation Winstone* 2000), Creative* 3D Blaster Annihilator 2 w/ nVidia* GeForce*2 GTS, IBM* DTLA-307030 ATA-100 hard drive, nVidia Detonator* 3 v6.18 graphics driver, Intel® Ultra ATA Storage Driver v6.02, Intel® chipset INF file v2.50, DirectX* 7.0b, Windows* 2000

Data Movement: Graphics BW

Pentium® 4 vs Pentium III Processor Write Combining



Partial writes reduce realized front-side bus B/W

- **~3x lower for Pentium III processor**
- **~7x lower for ~Pentium 4 processor (due to longer 64-byte line size)**